Experimental Results on Indirect Heating of Low Density Foam Layers

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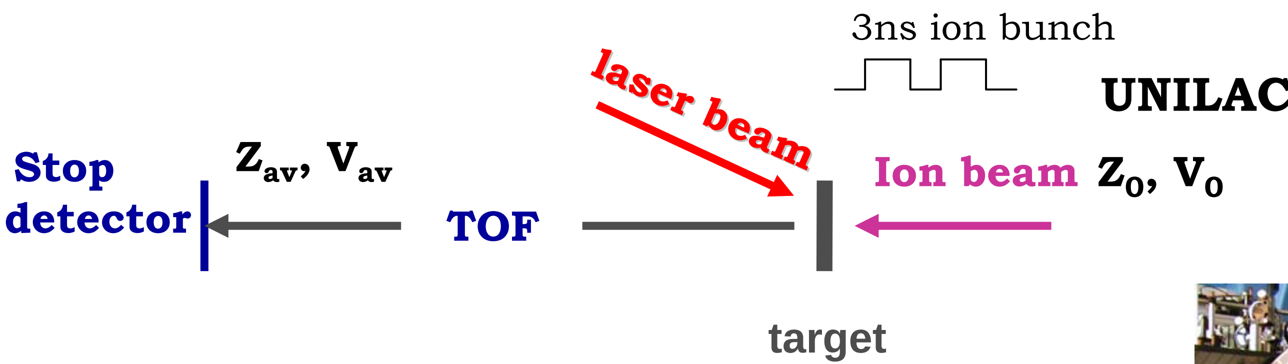
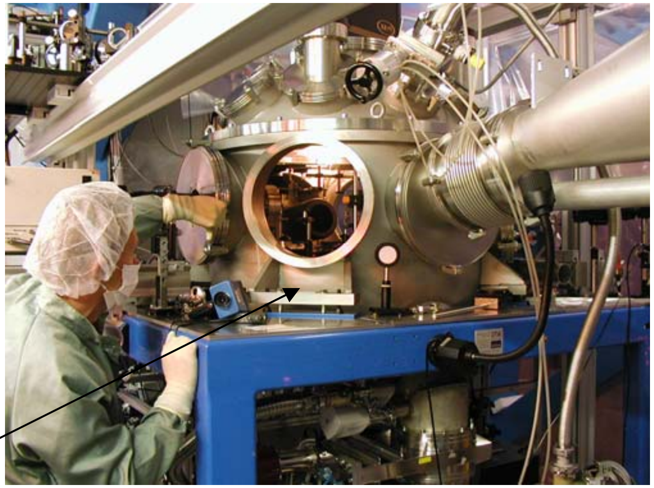
4h EMMI Workshop on Plasma Physics with Intense Heavy Ion and Laser Breams,
May, 2nd .- 4th, Darmstadt

Laser – Heavy Ion Beam Combined Experiments

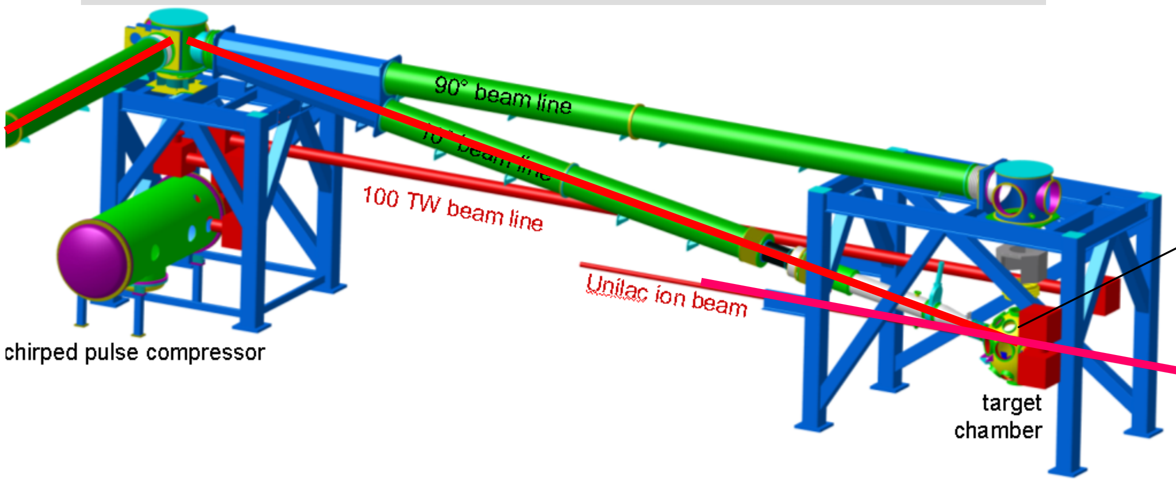
Interaction of heavy ions with ionized matter : increased plasma stopping power



Target chamber



PHELIX-laser : 0.3 kJ @ 1-15 ns, 1ω, 2ω (2011)

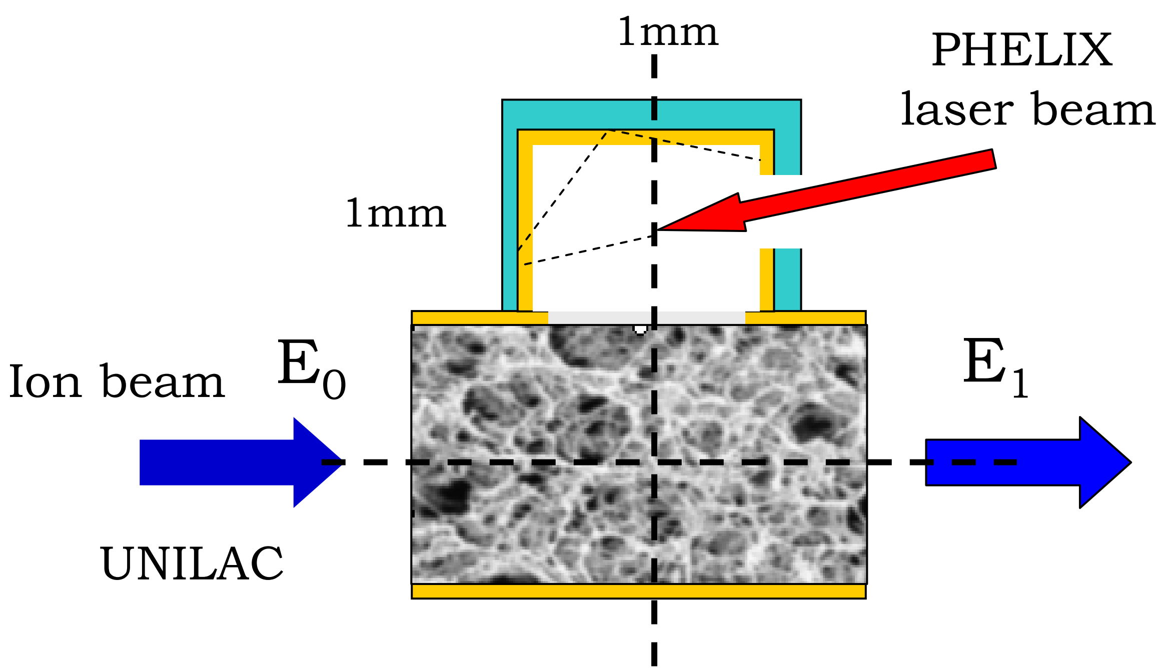


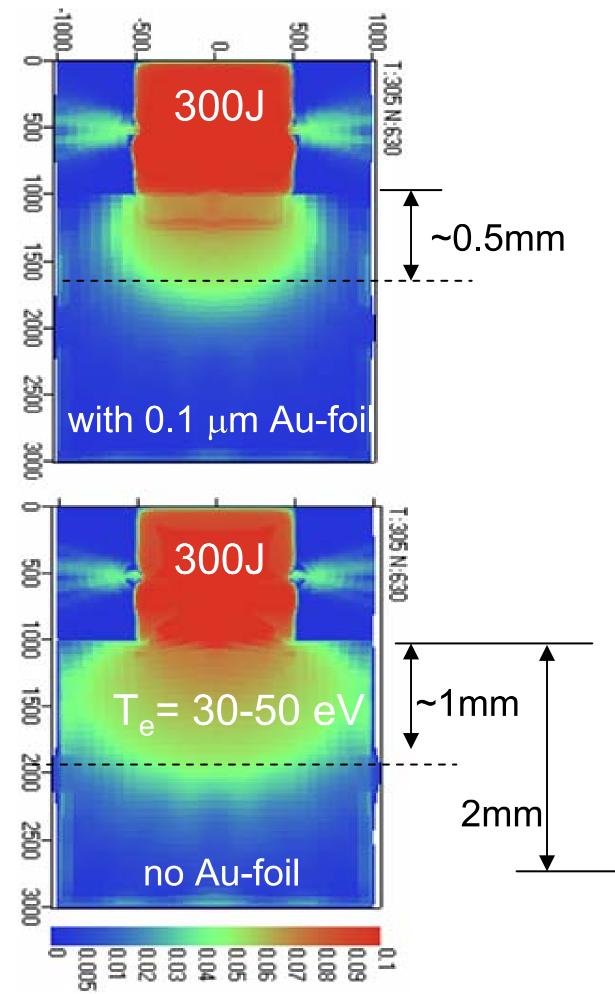
Heavy ion beam:
3<Z<92, E=3–13 MeV/u,
RF: 108/36 MHz

Numerical optimization of the plasma target geometry for heavy ion stopping experiments

Calculations for the current PHELIX parameters
300J, 1 ns, 250μm, 1ω, 10 degree beam-line

2-D hydrodynamics combined with
2-D multi group radiation transport





VNIIEF, Sarov, Nov. 2009

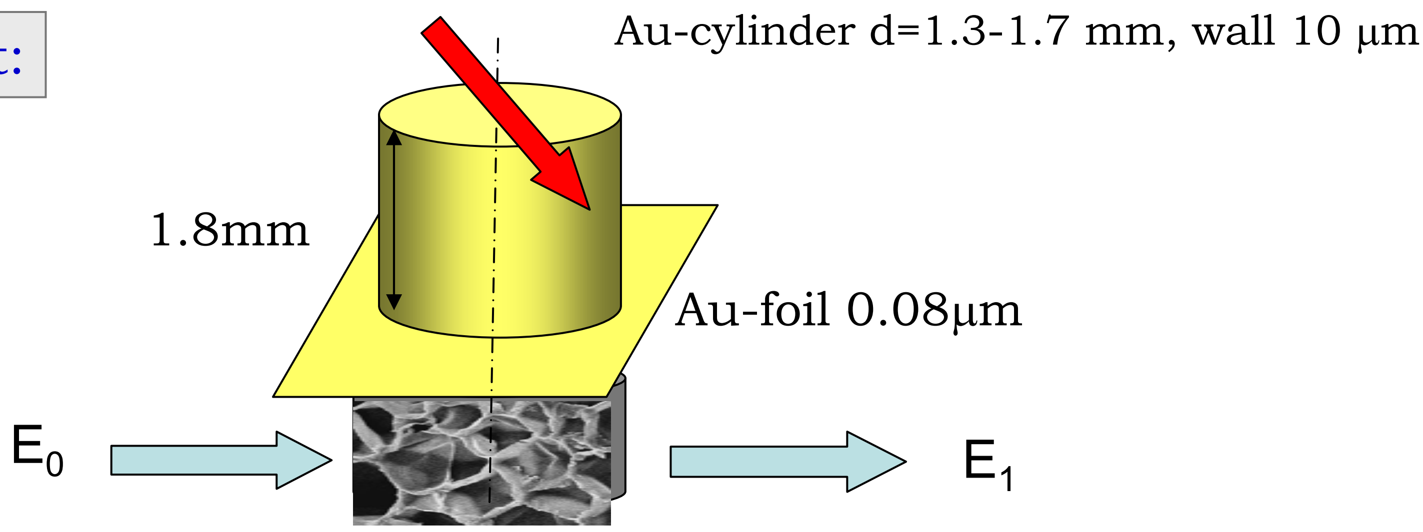
Heating of low Z foams by means of hohlraum radiation

creation of large (1mm X 1mm), homogeneous, long leaving (>3 ns - length of the ion bunch) partially ionized plasma of $n_e \sim 10^{20}\text{-}10^{21} cm^{-3}$

PHELIX Laser:

λ=1,06/0.53 μm, τ =1.4/1 ns,
E= 200-270/100-150 J,
d~200-300μm, I>10^{14} W/cm^2, contrast 10^{-6}

Target:



Heavy ion beam
4-6 MeV/u
d~500μm
τ=3ns

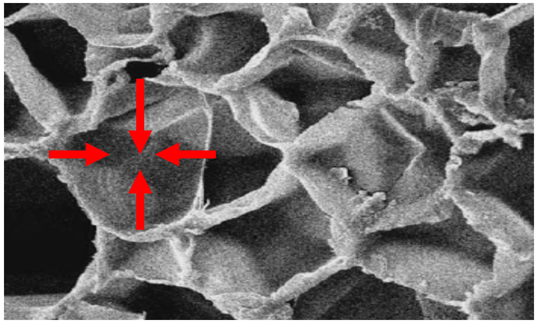
CHO-foam 2-20 mg/cm^3

areal density ρx~ 150-500 mg/cm^2

Why foams?

Properties under the ion and laser beams:

1. Higher conversion of laser energy in to the plasma temperature compared to the solid foils

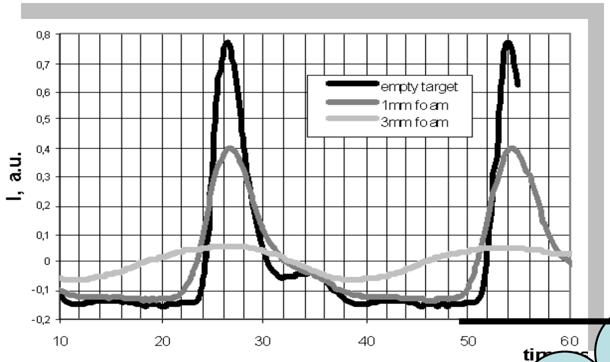


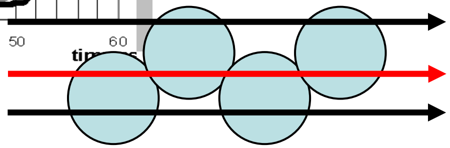
2. Slow expansion dynamics (ρ, T ~ constant during nanoseconds)

3. Fast (~sub ns) homogenization after laser heating

$mv_i^2 \Rightarrow T_i \Rightarrow T_e$

4. Energy broadening of the ion bunch caused by the porous structure has to be acceptable (no merging of the subsequent ion bunches)





Small pore size is important!

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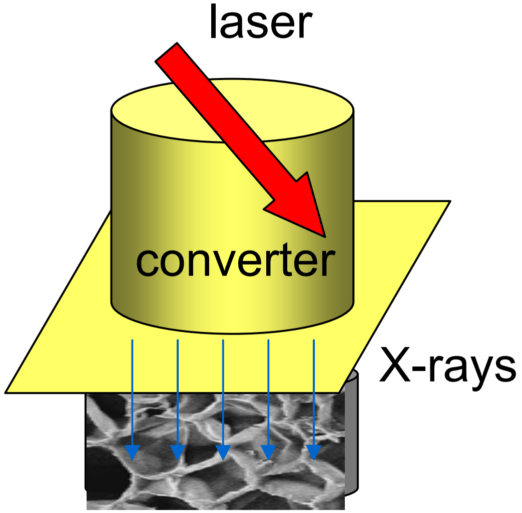
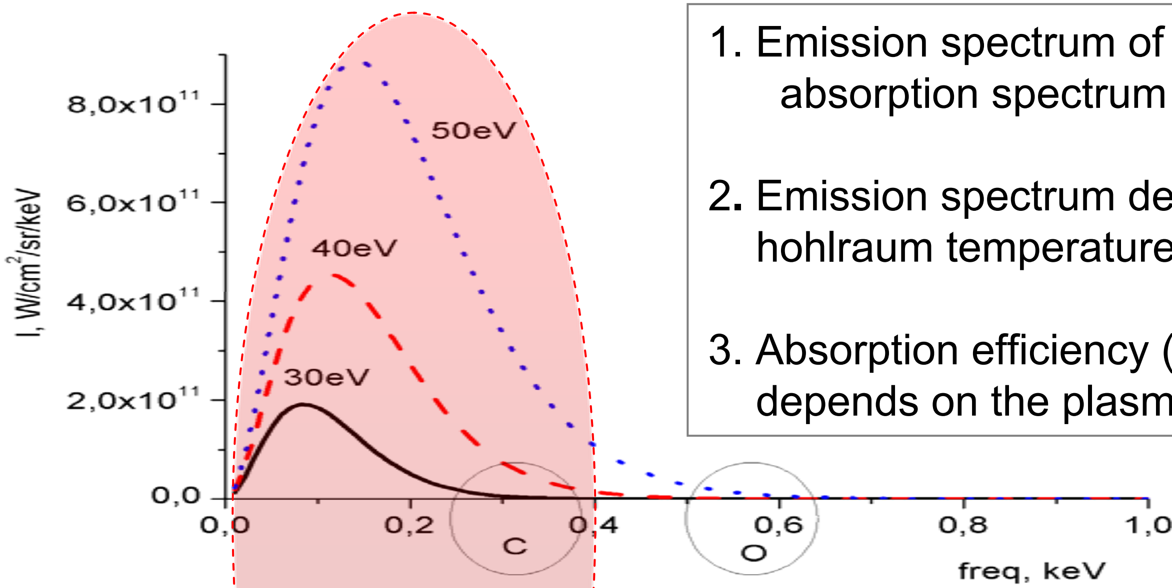
What we would like to know?

1. Radiation field of the primary hohlraum (converter)
2. Conversion efficiency of the laser energy into soft X-rays
3. Absorption properties of CHO-foams
4. Temperature and ionization degree of heated by X-rays CHO-plasma

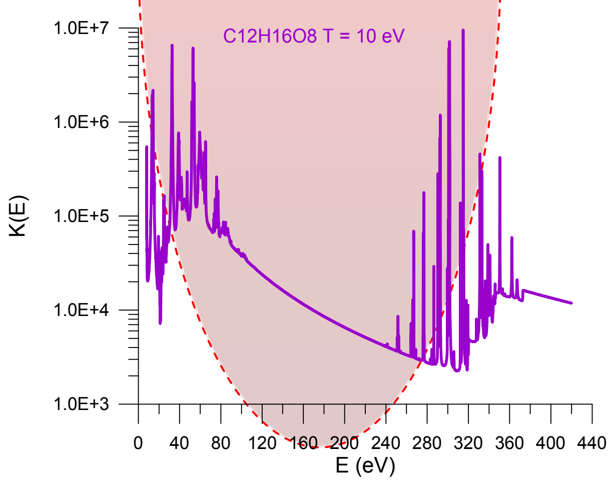


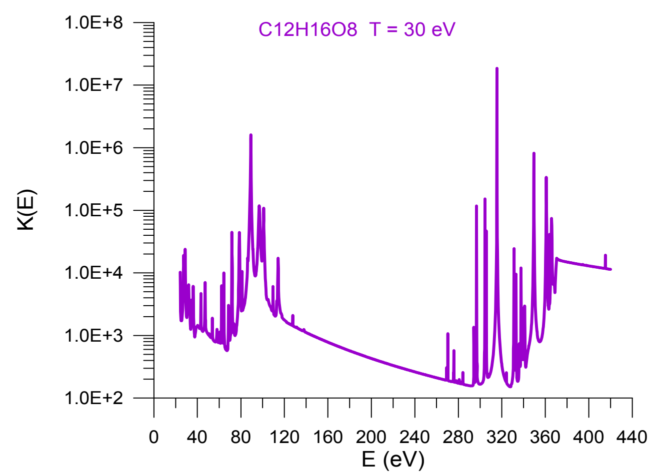
Effective heating of targets by X-rays

Hohlraum: Planckian spectral distribution of the X-ray source emissivity



1. Emission spectrum of the X-ray source overlaps with absorption spectrum of the heated material (Au –> C,O)
2. Emission spectrum depends on the hohlraum temperature (Planck)
3. Absorption efficiency (for the given target material) depends on the plasma temperature





Absorption coefficients of CHO-plasma

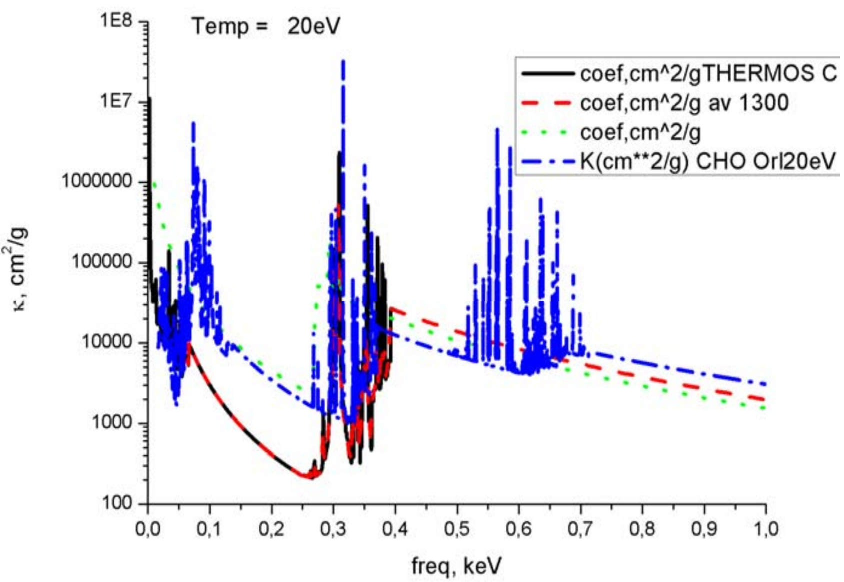
N. Orlov, JIHT,Ras, Moscow

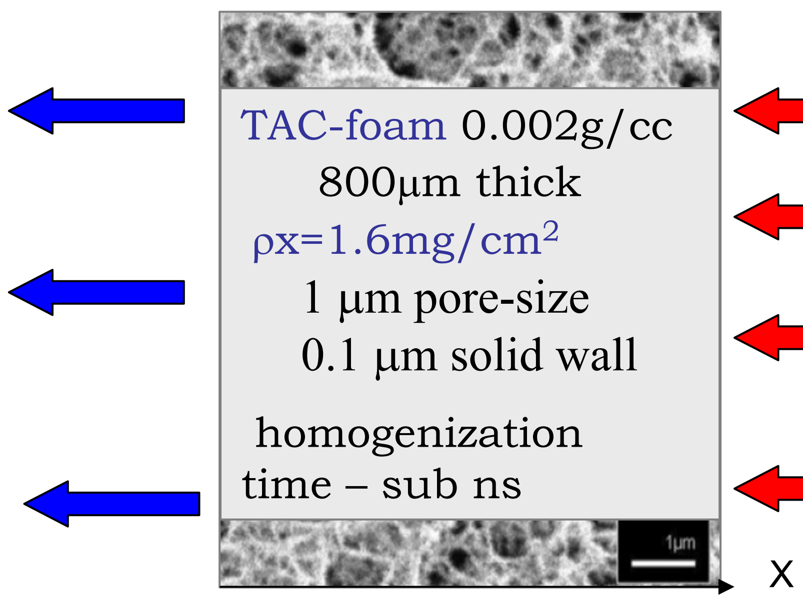
HD of CHO-foam heated by the external X-ray source: Planck, T_{rad}=20-40eV, $t_{x\text{-}rays}$ = 5ns

Code RADIAN: two-temperature hydrodynamics with radiative transfer equation using TAC-foam opacities calculated by N. Orlov, JIHT

transmitted + plasma self rad.

Incident radiation





Planckian radiation

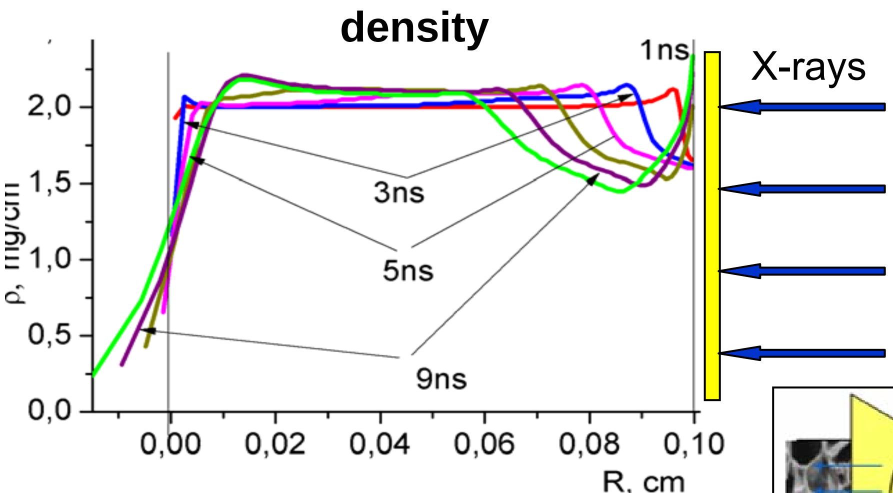
What we would like to know: Te (x, time)=?, ρ (x, time)=?

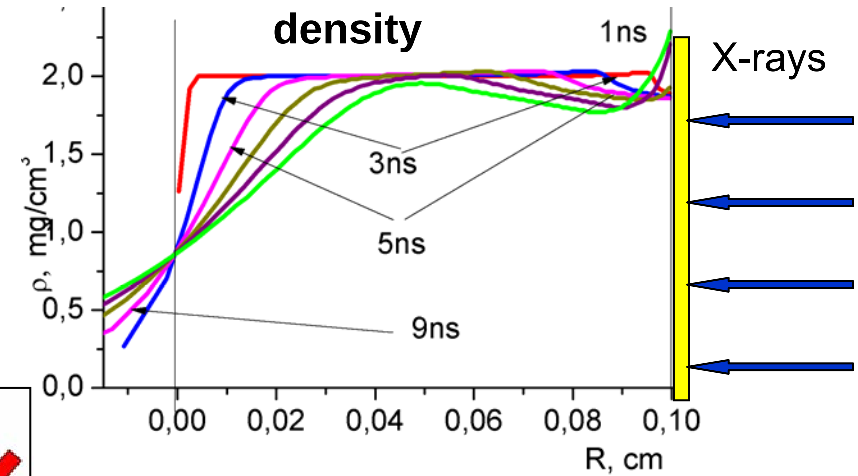
G. Vergunova, LPI, Moscow

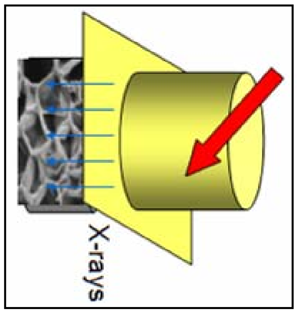
Temporal profiles of plasma density and temperature

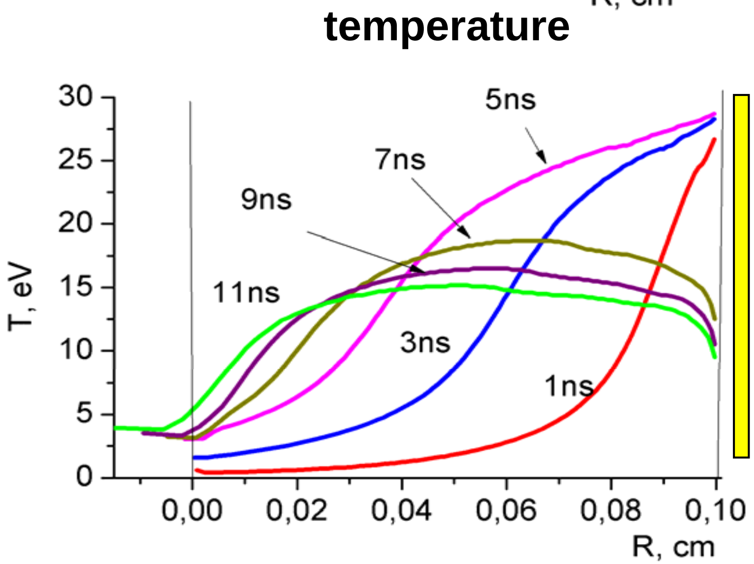
N 315. Incident flux Planck :Trad=**30eV**, τ_{rad}=5ns.
Target TAC, Δ=1000μm, ρ=0.002g/cc.
Optical coefficients calculated by Orlov.

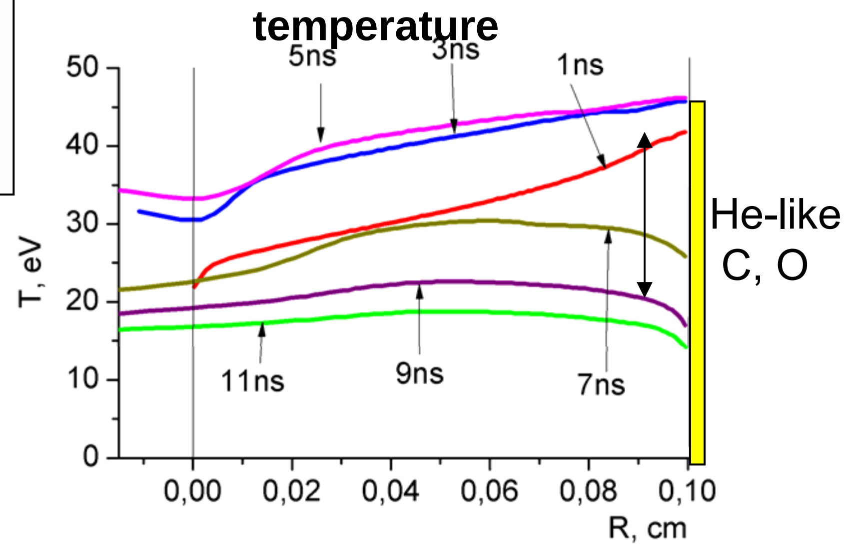
N317. Incident flux Planck :Trad=**50eV**, τ_{rad}=5ns.
Target TAC, Δ=1000μm, ρ=0.002g/cc.
Optical coefficients calculated by Orlov.









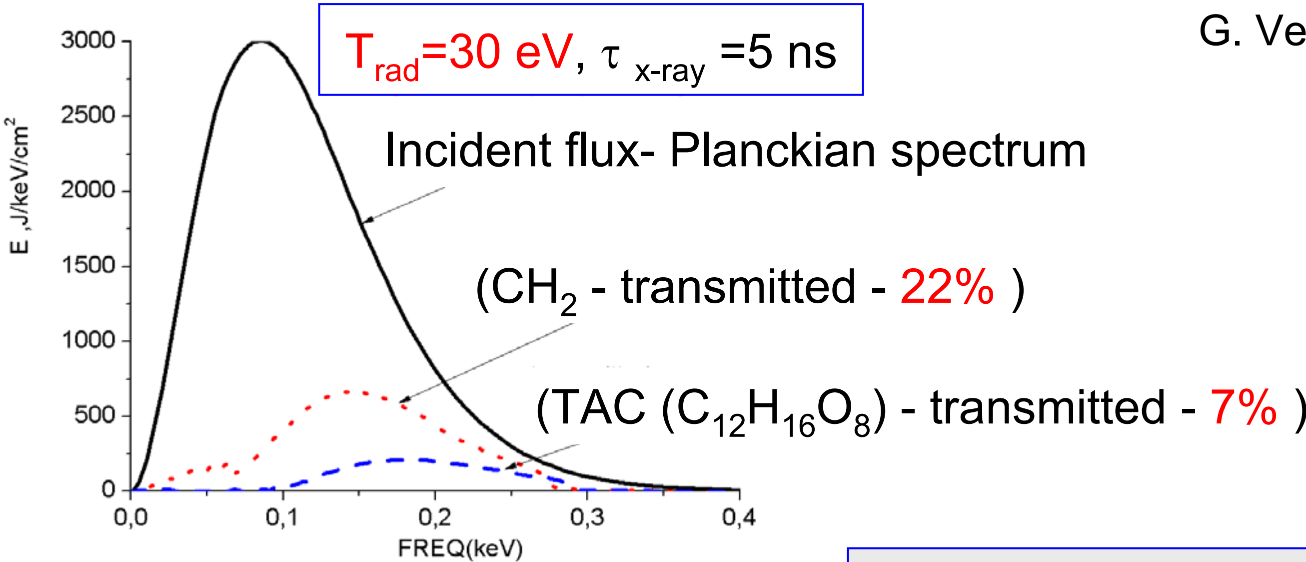


Te distribution heterogeneous up to 5ns

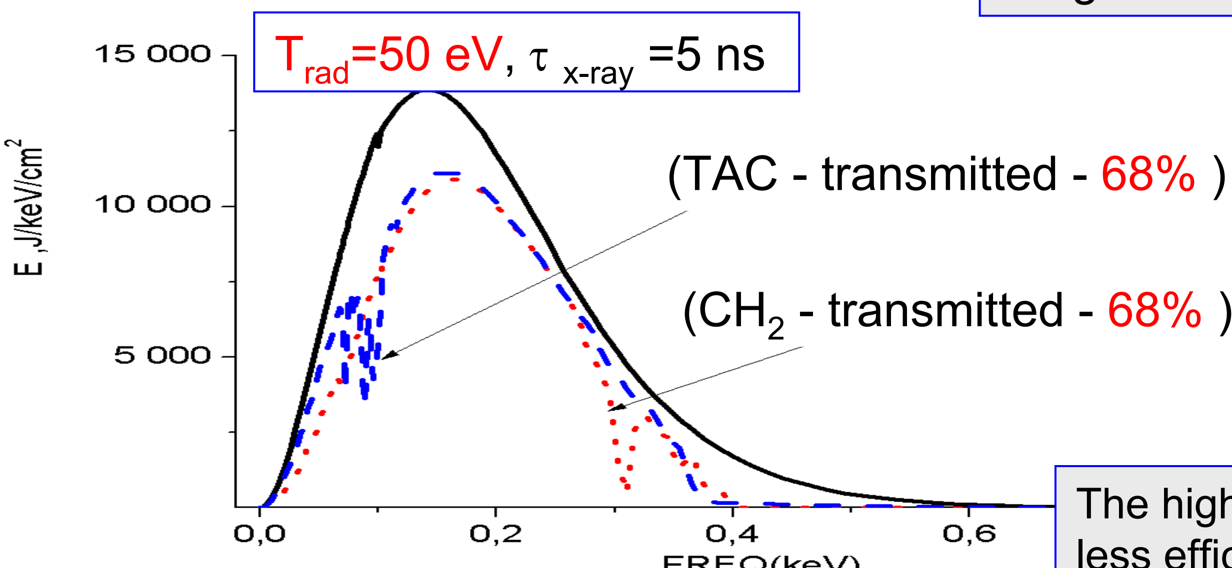
homogeneous at τ > 1 ns!

Transmitted hohlraum energy in dependence on plasma temperature and target chemical composition

G. Vergunova, LPI, Moscow.

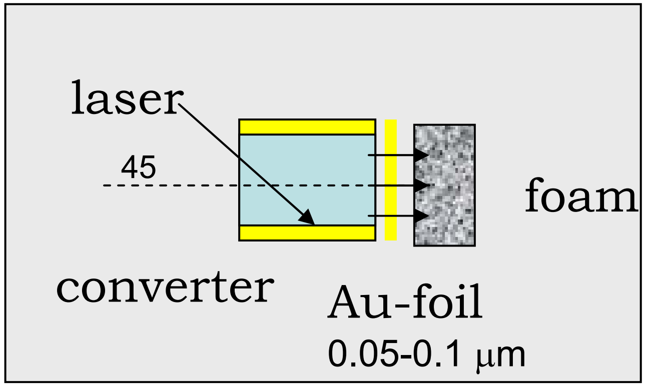


Target : 1000 μm 2 mg/cc TAC or CH_2

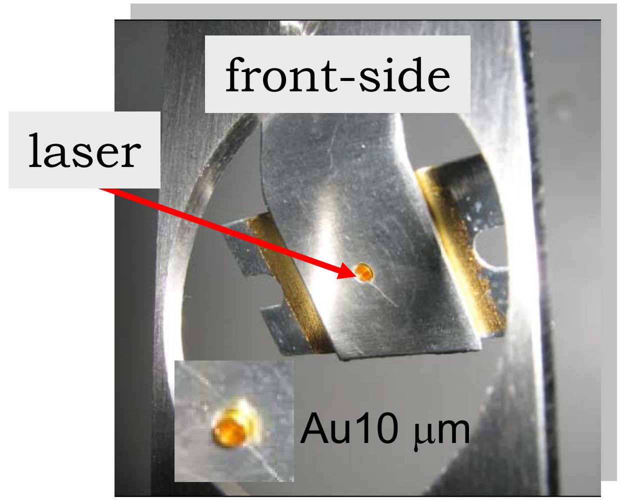


The higher is hohlraum temperature the less efficient is foam heating by X-rays

Combined targets: converter - foam

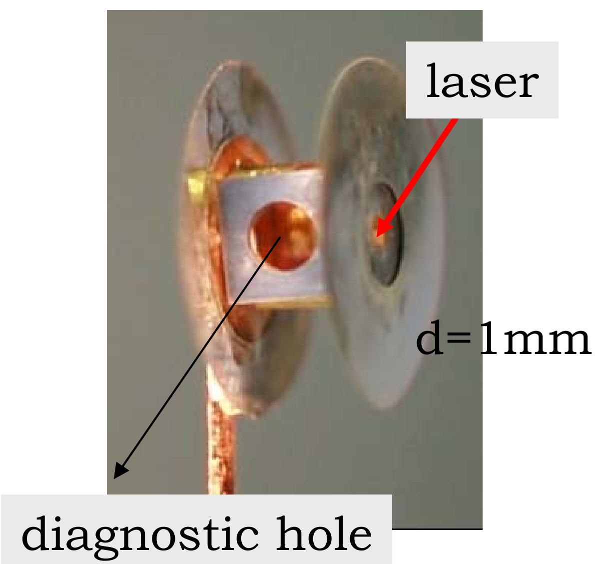


GSI-converter



GSI-converter+foam

Sarov-converter



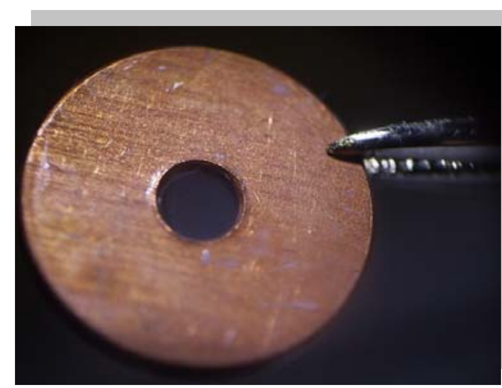
cellulose triacetate

3-D regular network with
open cell structure,
the most fine pore
structure (~ 1μm)
remains stable up to 220C

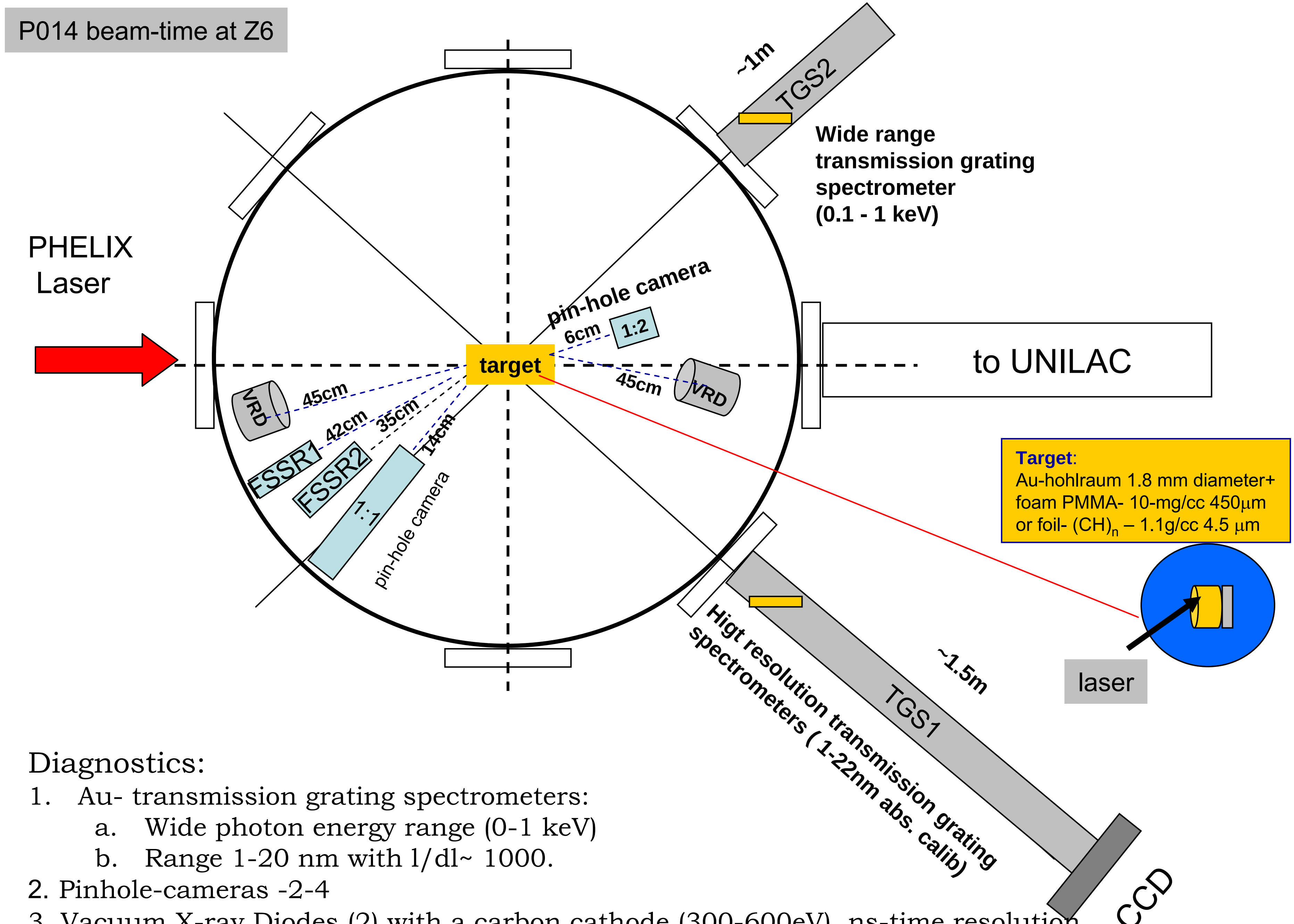
used at PALS, LIL, GSI

N. Borisenko, LPI, Moscow

TAC($C12H_{16}O_8$)



2mg/cc 800-1000μm

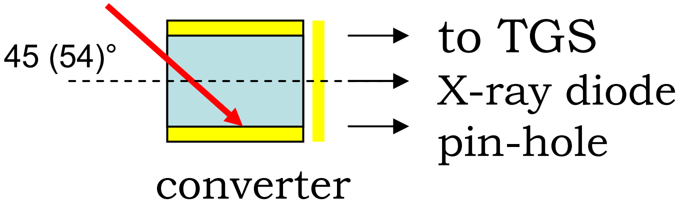


Diagnostics:

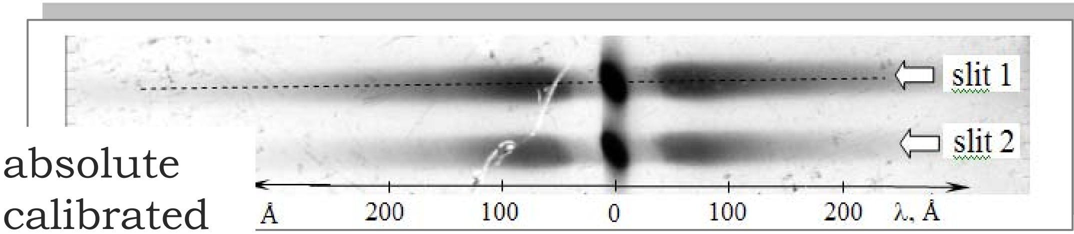
1. Au- transmission grating spectrometers:
   a. Wide photon energy range (0-1 keV)
   b. Range 1-20 nm with l/dl~ 1000.
2. Pinhole-cameras -2-4
3. Vacuum X-ray Diodes (2) with a carbon cathode (300-600eV), ns-time resolution
4. FSSR-mica Spectrometer for Au-radiation in 1-2 keV photon range

Results (1ω): Diagnostics of the converter radiation field

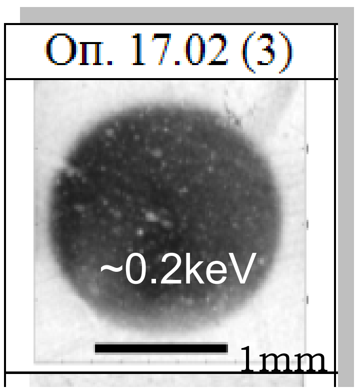
Laser
~250J, 1.4 ns



Transmission Grating Spectrometer (Sarov)

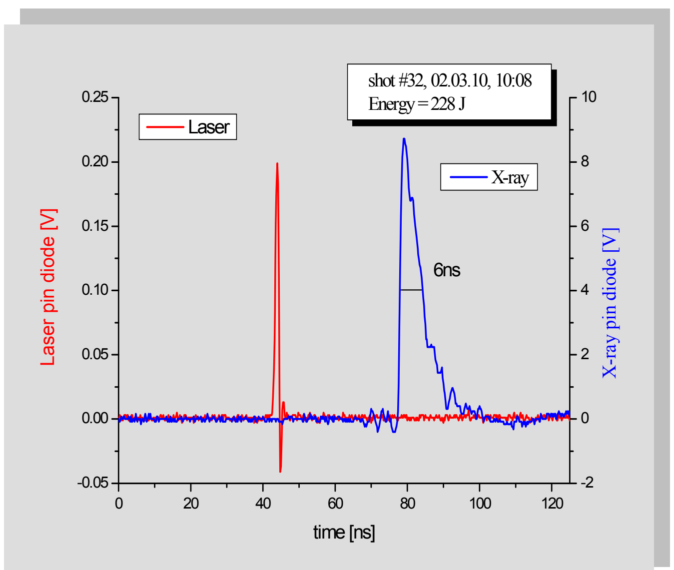


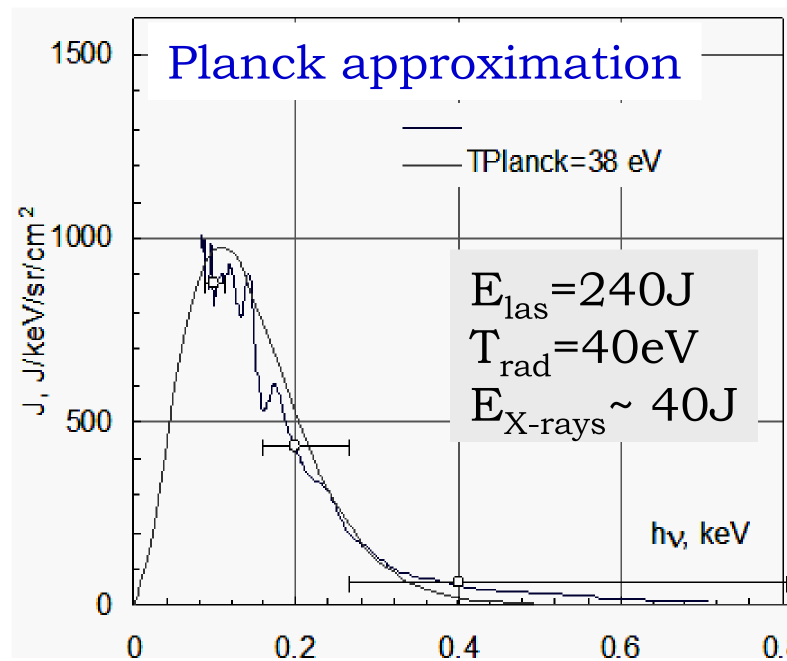
absolute calibrated UV-film



pin-hole image of the hohlraum in 0.2-0.28 keV

Soft X-ray signal ~ 6ns (laser pulse-1.4ns)





N. Suslov, A. Kunin, N. Zhidkov, Sarov

Main results: Converter (primary hohlraum)

By irradiation of the primary hohlraum with 230-270J laser energy (1.4ns, λ=1.054 μm) we create

uniform 1.7 mm soft X–ray source

Soft X-ray pulse duration

$\tau_{x\text{-rays}}$ = 5-7 ns

Hohlraum equivalent radiation temperature

T_{rad} = 30-40eV

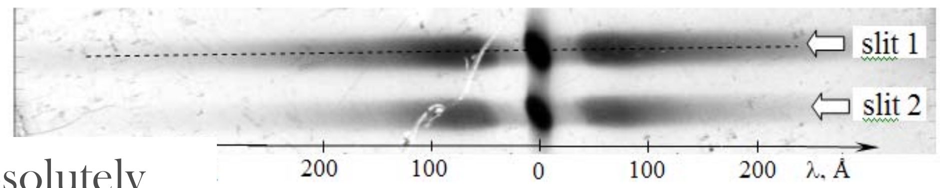
Conversion efficiency of laser energy into X-rays

up to 17% (1ω)
40J in soft X-rays

Absorption of soft X-rays by foam layer: four fold attenuation of the converter radiation by plasma

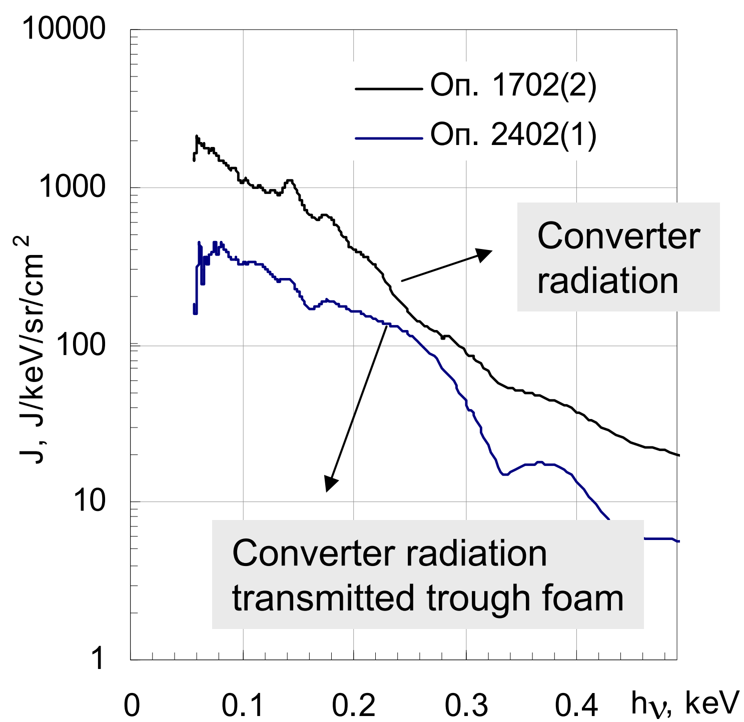
Shot 17.02.10(2) E=120J

Target: converter d=1.7mm,h=1.7mm, wall 10 μm Au, bottom Au 168μg/cm²



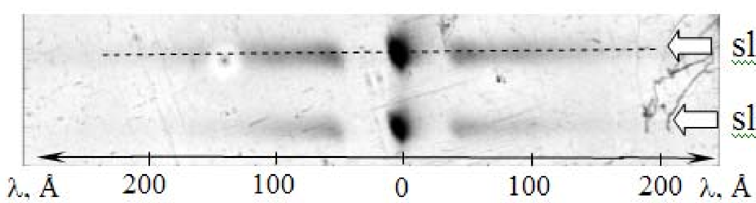
absolutely calibrated XUV-film

75% of the hohlraum radiation in the range 60-1200eV is absorbed in CHO-plasma



Shot 24.02.10(1) E=130J

Target: converter+ 0.002g/cc 800μm TAC



results N. Suslov, VNIEF, Sarov

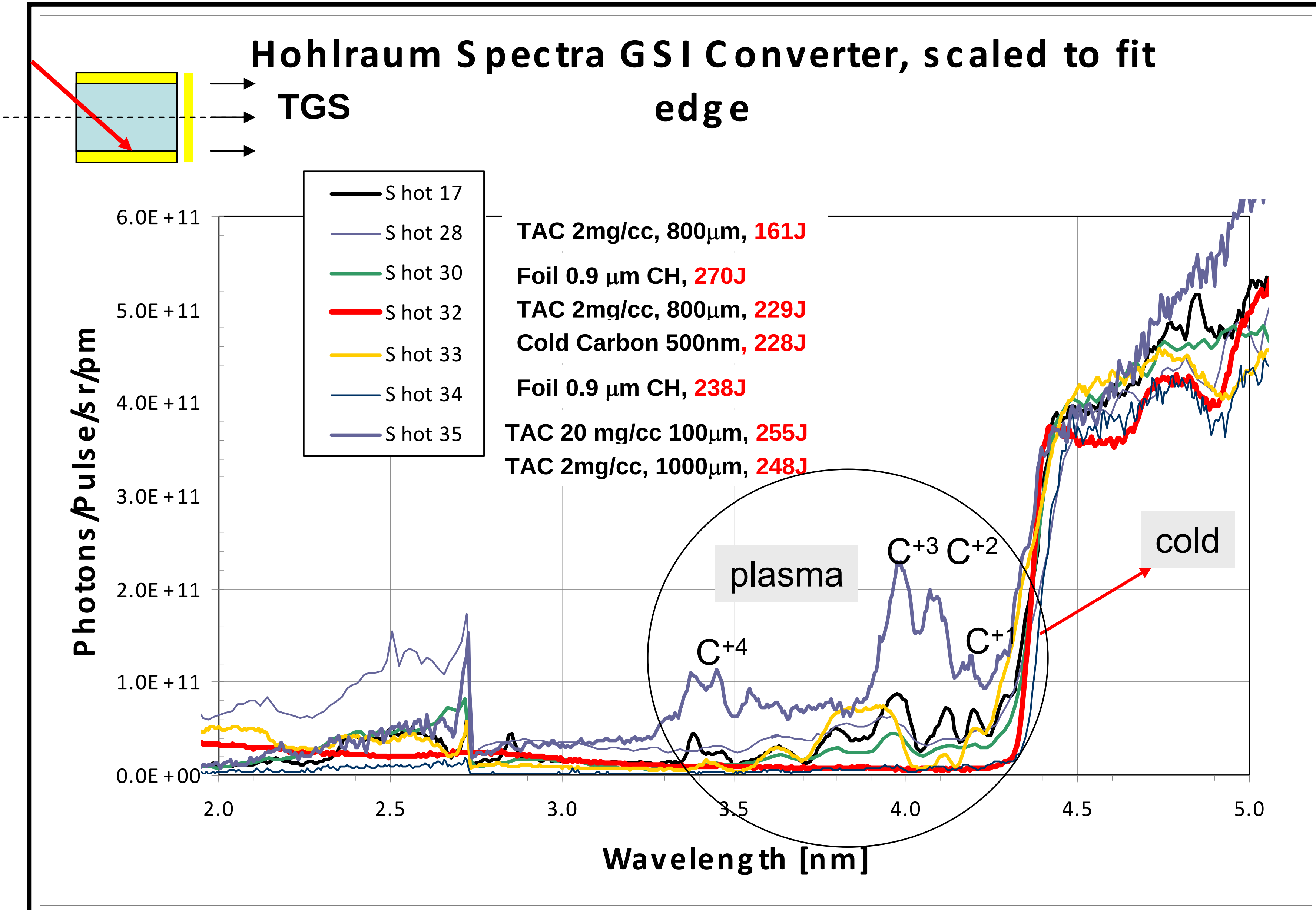
Main results: absorption of X-rays in the foam target

Amount of X-ray energy absorbed in foam targets

up to 30 J energy in soft X-rays (60-1200eV)

What is temperature of CHO-plasma?

Absorption spectra of ionized Carbon in heated by X-rays foams and foils

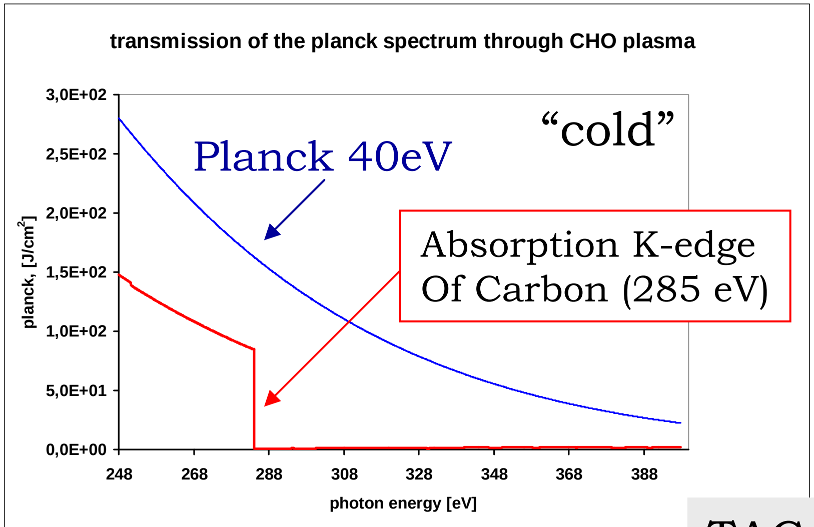


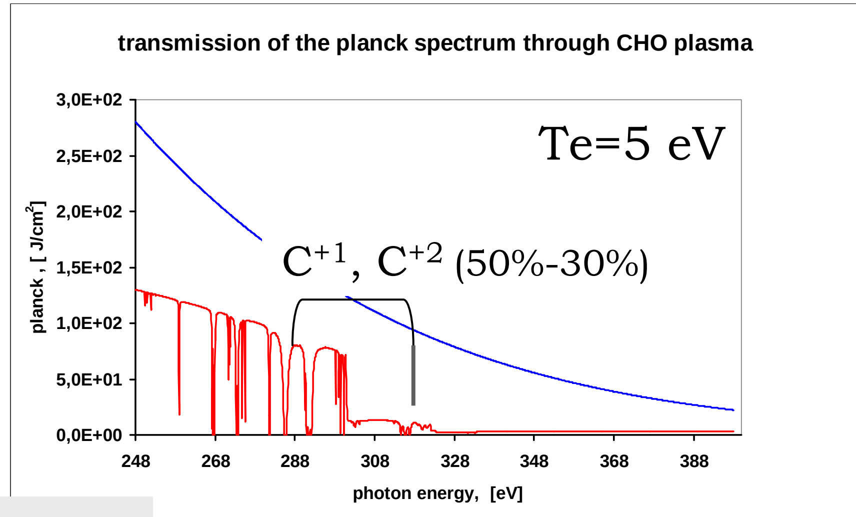
D.Schäfer, Th. Nisius, Th. Wilhein, Remagen

Absorption properties of CHO plasma

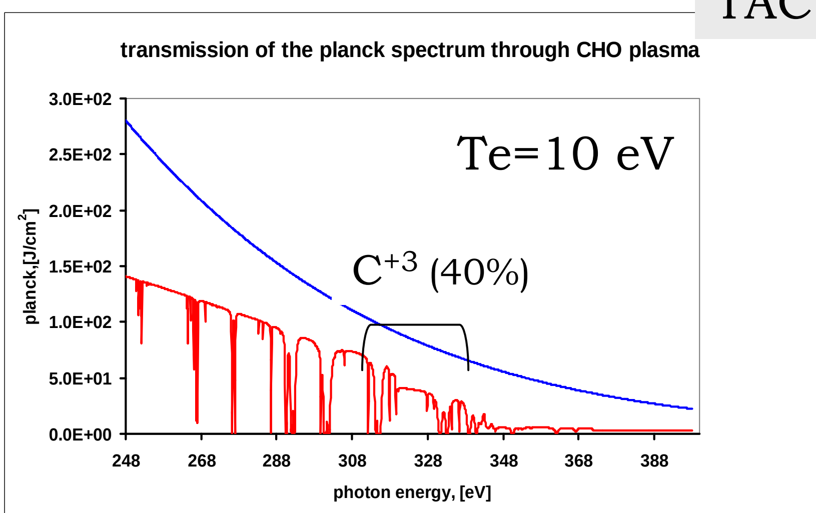
Nikolay Orlov, JIHT, Moscow

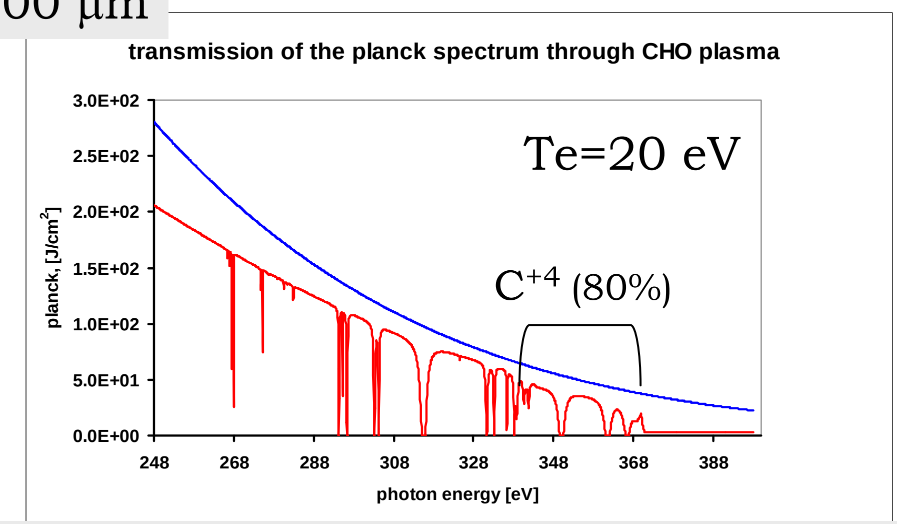
Dependence on plasma temperature/ionization degree





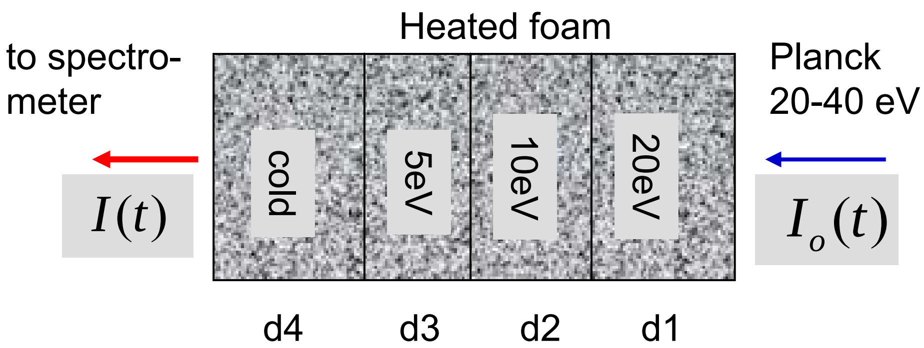
TAC 800 μm





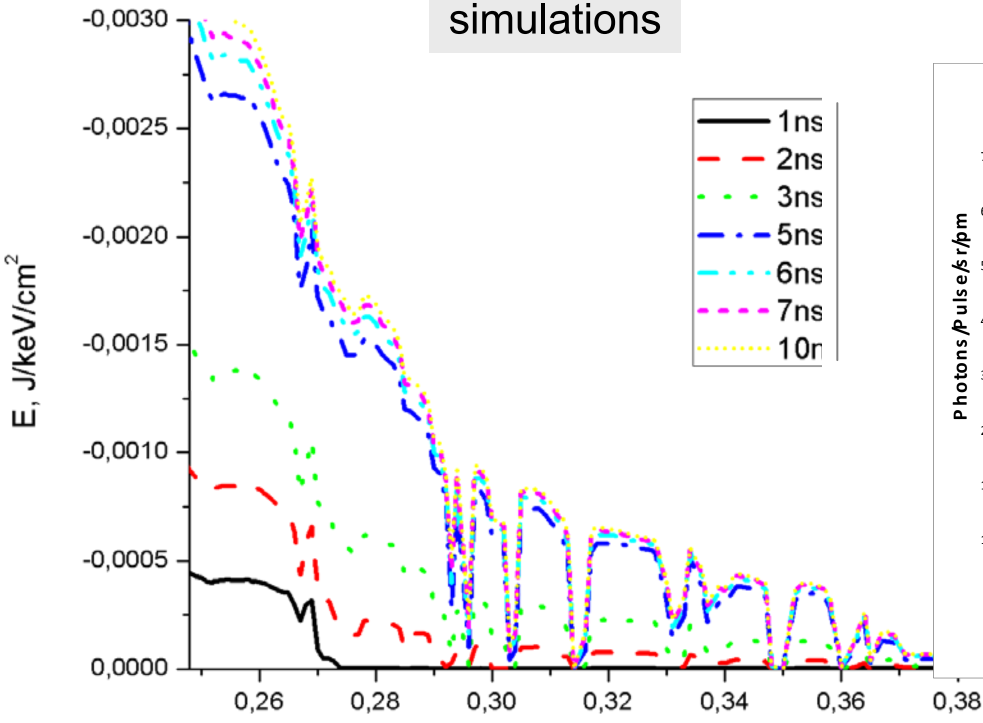
Calculated for homogeneous temperature distribution over the foam thickness

Simulations of the transmitting through CHO-plasma hohlraum spectrum using results of HD calculationss



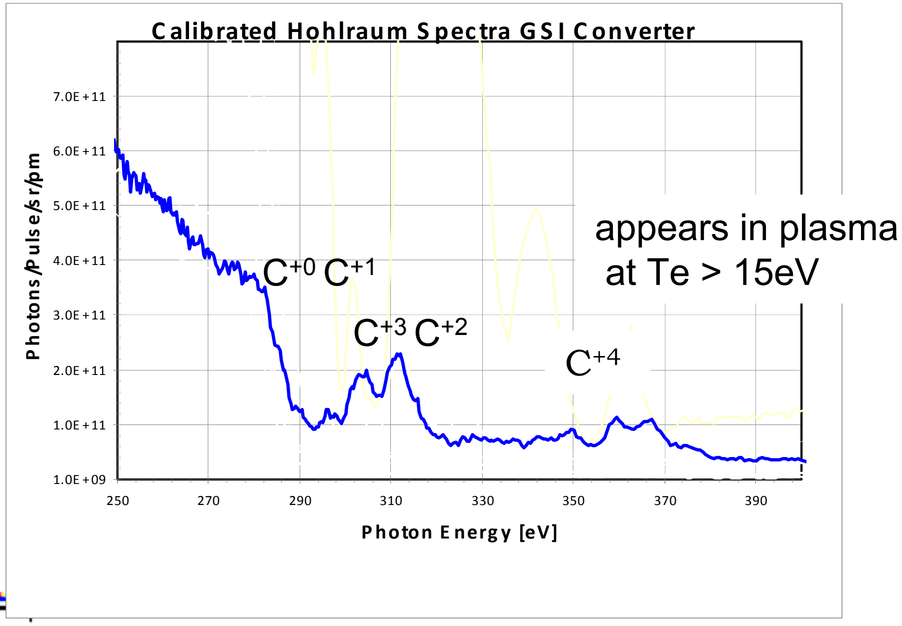
$$\int I(t)dt = \int dt \cdot I_o(t) \cdot \sum_i e^{-\rho_i(t) \cdot k_i(t) \cdot d_i(t)}$$

simulations



photon energy, keV

experiment



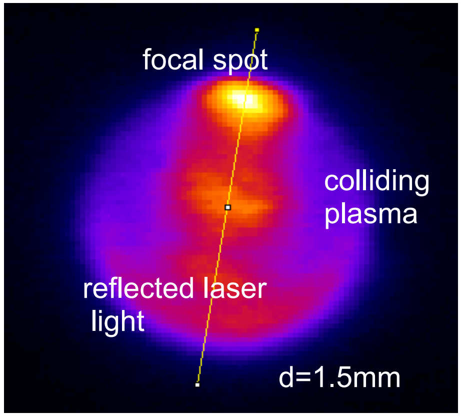
G. Vergunova, N. Orlov

PHELIX: 2ω Beam-time March,1- 4, 2011

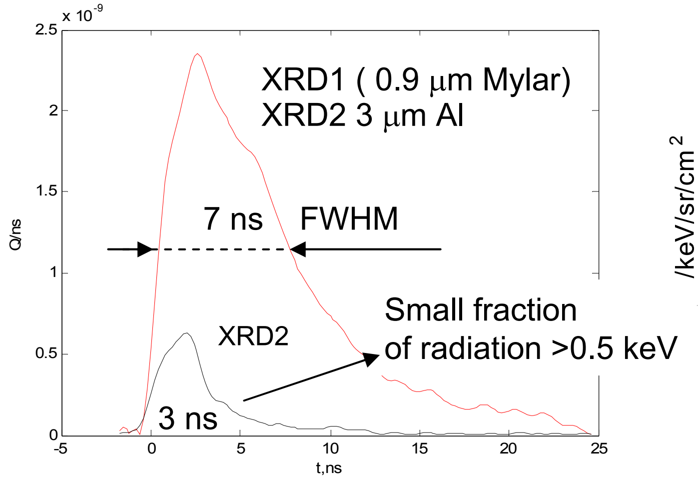
Laser: E=100-150J t=1ns; d=200-300 μm $I = 2\text{-}\ 4.\ 0^{14}$ W/cm^2

Target: gold hohlraum d=1.3-1.5mm; foam: TAC 2 mg/cc thickness 0.5 – 1mm

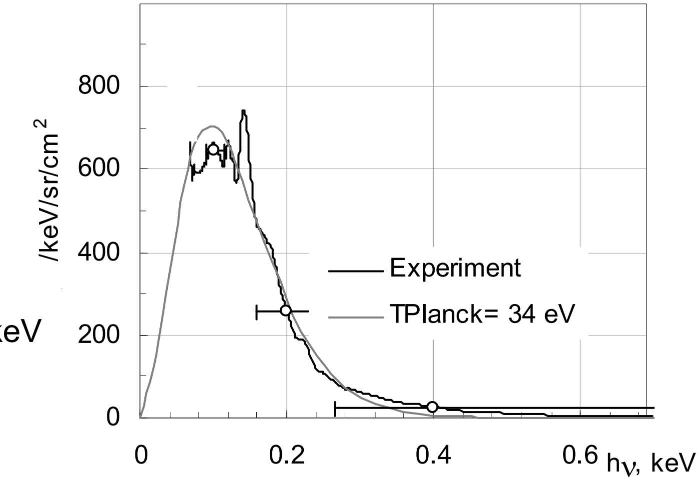
X-ray pin-hole image



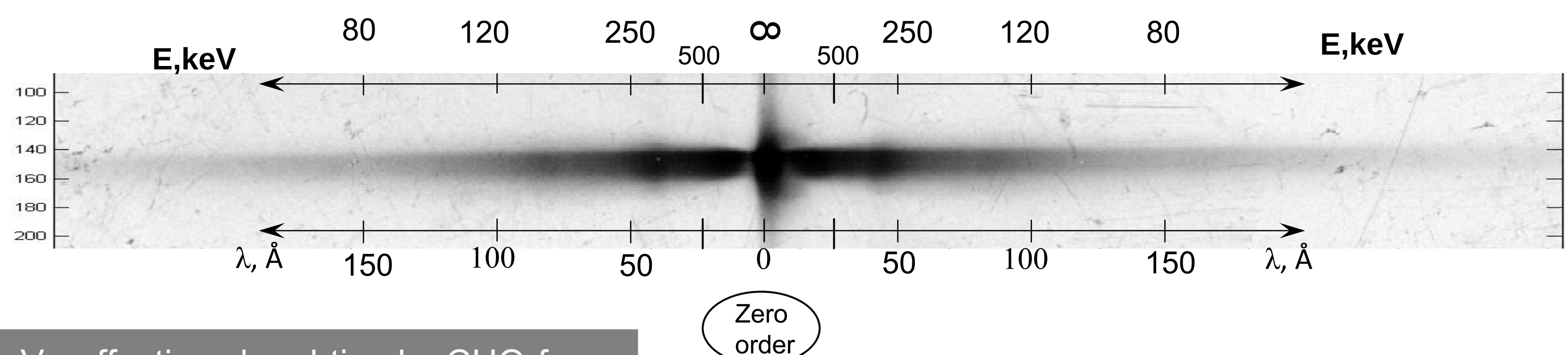
X-ray photo diodes



Equivalent Planckian temperature



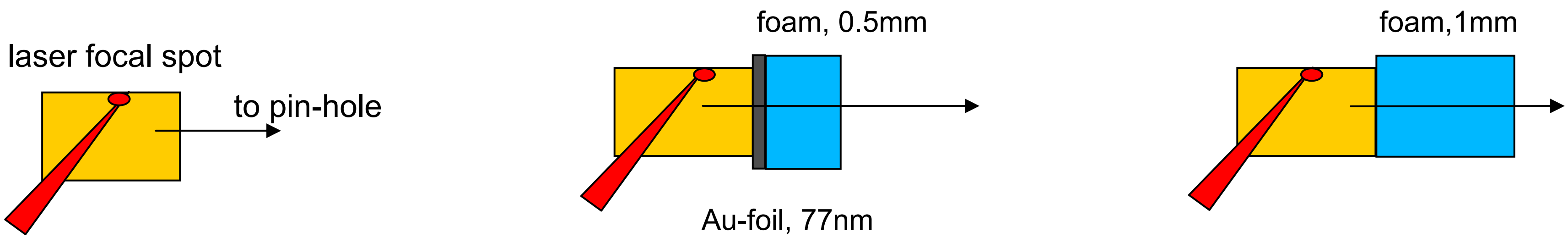
Spectrum of Au-hohlraum (transmission grating spectrometer (TGS))



<500eV - effective absorbtion by CHO-foam

X-ray imaging of hohlraum plasmas

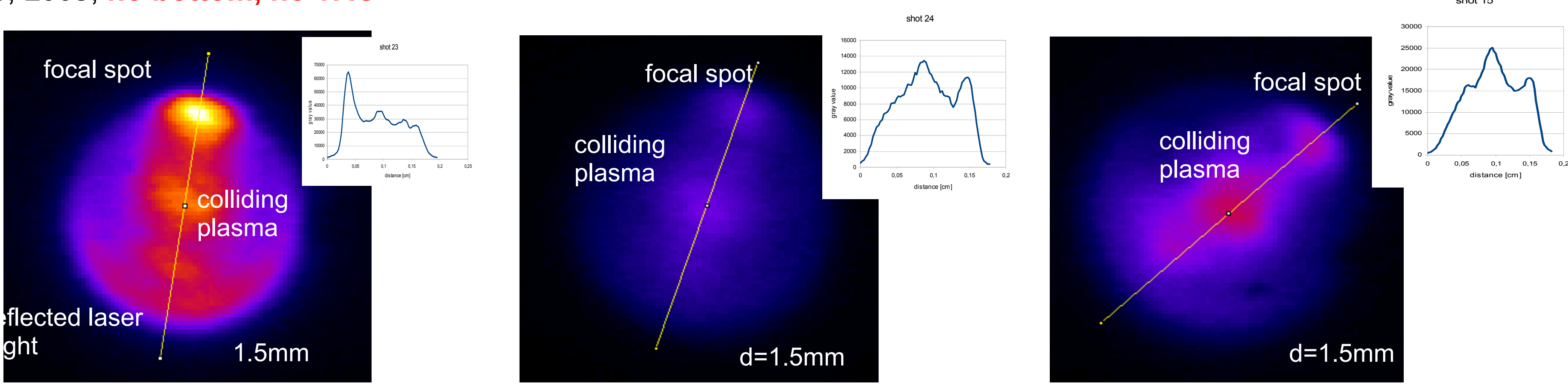
back –side



Sh23, **100J**, **no bottom, no TAC**

Sh24, **104J** (77nm Au + 500 um TAC)

Sh15, **117J** (no bottom, 1000 um TAC)



Results on indirect heating of foam targets

Converter:

- X-ray source:
  T_{rad}= 30 - 40eV   d=1.3-1.7mm t = 5-8ns

- $E_{x\text{-}rays}$~40J ; up to17% of the laser energy (1ω)
  at 2ω –up to 40% (beam-time 1-4.03 2011)

- $I_{x\text{-}rays}$= 2. 10^{11} W/cm^2

Foam:

- Effective (75-90%) absorption of soft x-rays (50-1000eV)

- Deformation of K-edge: diagnostic of the plasma temperature and ionization degree.

- Data on the dependence of the foam-layer transmission on the layer thickness and converter temperature

Beam-time March 2011